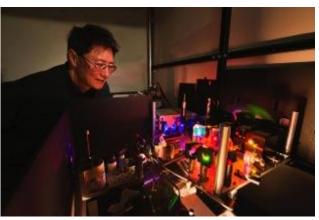
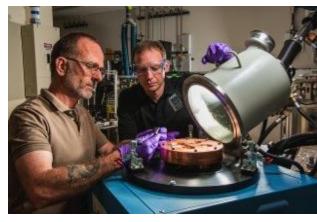
Exceptional service in the national interest









Sandia National Laboratories / Energy Storage Program: An Overview

Dr. Stanley Atcitty (Stan), Acting Manager

Energy Storage Technology and Systems Dept. – August 2015



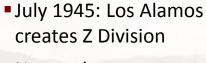


Sandia's History





Exceptional service in the national interest



Nonnuclear component engineering

■ November 1, 1949: Sandia Laboratory established

> to undertake this task. In my opinion you have here an opportunity

to render an exceptional service in the national interest.

THE WHITE HOUSE

merican Telephone and Telegraph Company,









Governance of Sandia Laboratories Sandia Corporation



AT&T: 1949–1993

Martin Marietta: 1993–1995

Lockheed Martin: 1995–present

Existing contract expires: April 30, 2016, with a one-year contract extension option



Sandia Sites





Our Core Values



- Serve the nation
- Deliver with excellence
- Respect each other
- Act with integrity
- Team for great results



Strategic Plan





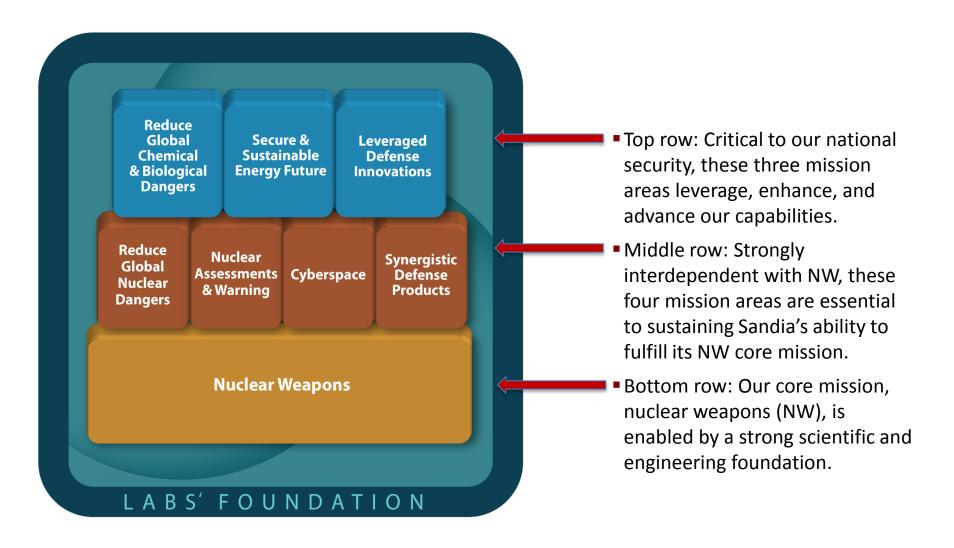
Strategic Objectives

- Deliver with excellence on our commitments to the unique nuclear weapons mission
- Amplify our national security impact
- Lead the Complex as a model 21st century government-owned contractor-operated national laboratory
- Excel in the practice of engineering
- Commit to a learning, inclusive, and engaging environment for our people



National Security Mission Areas





Sandia Addresses National Security Challenges





1950s 1960s 1970s **2000s** 1980s 1990s **2010s Nuclear weapons** Development Multiprogram Missile defense **LEPs** Post-Cold War **START** engineering laboratory work transition Post 9/11 Cyber, biosecurity proliferation **Production and** manufacturing **Evolving national** Stockpile engineering security challenges Vietnam conflict stewardship **Energy crisis Cold War National security**

Energy & Climate







Energy Research

ARPAe, BES Chem Sciences, ASCR, CINT, Geo Bio Science, BES Material Science

Climate & Environment

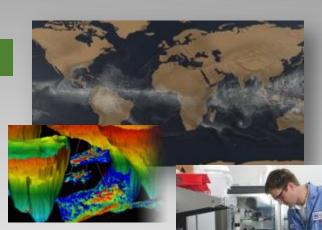
Measurement & Modeling, Carbon Management, Water & Environment, and Biofuels

Renewable Systems & **Energy Infrastructure**

Renewable Energy, Energy Efficiency, **Grid and Storage Systems**

Nuclear Energy & Fuel Cycle

Commercial Nuclear Power & Fuel, Nuclear Energy Safety & Security, DOE Managed Nuclear Waste Disposal



Transportation Energy & Systems

Vehicle Technologies, Biomass, Fuel Cells & Hydrogen Technology



Our Workforce



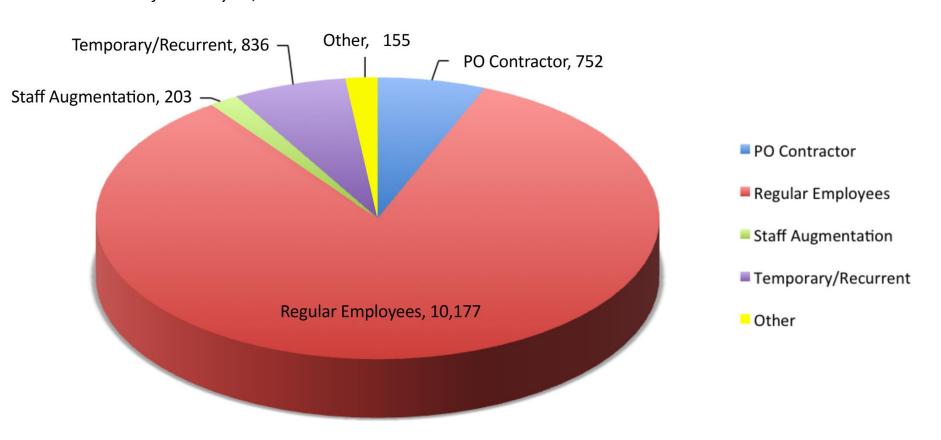


■ Total Sandia workforce: 12,123

■ Regular employees: 10,177

Advanced degrees: 6,097 (59%)

Data as of February 27, 2015



Exceptional Service in our Community





United Way in Calendar Year 2014

Total: \$6.7M

NM 2014 results: \$6.52M, including \$840,900 from retirees

CA 2014 results: \$184,238

Sandia exceeded last year's giving by over 8%

NM Participation in 2013: 75% NM Participation in 2014: 77%













Department of Energy Office of Electricity Delivery & Energy Reliability (OE) Sandia National Laboratories Energy Storage Program

Energy Storage Is Critical to the Stability and Resilience of the Electric Grid





Traditional Grid

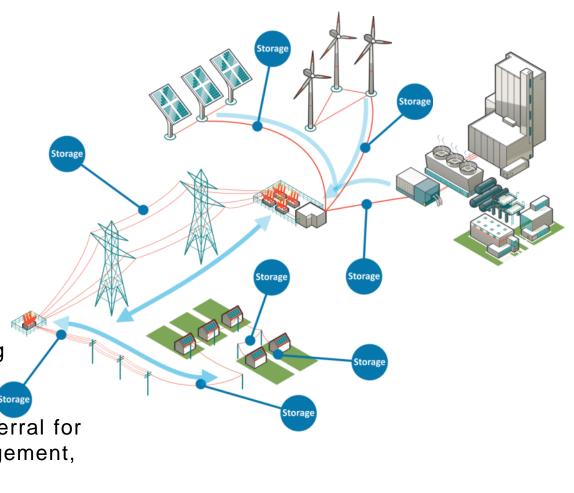
- One way flow
- Little/no renewable energy

Today's Grid

 Integration of grid-scale and distributed renewable generation beginning, but with limited penetration

Future Grid

- Storage provides buffering capability to enable high penetration of variable renewables and asset deferral for T&D systems (load management, ancillary services)
- Efficient two-way flow



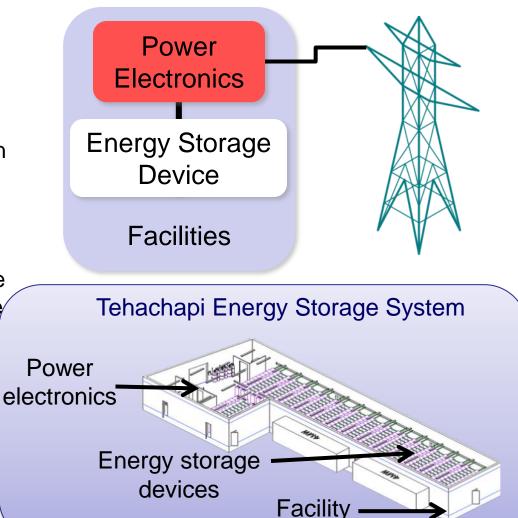
Energy Storage System Configuration





Energy Storage Systems contain three major components:

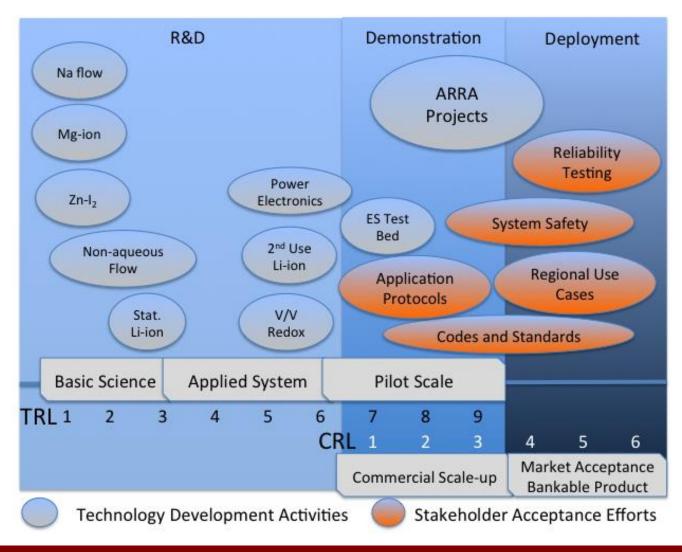
- Energy storage device
 - Where energy is held until needed
 - Ex: chemical/electrolyte (used in battery), flywheel, etc.
 - ~25-40% of overall costs
- Power electronics
 - Ensures proper and safe charge and discharge of storage device and can provide grid support
 - ~20-25% of overall costs
- Facilities (balance of plant)
 - Houses all equipment, protects system from physical damage
 - Can include HVAC
 - ~20-25% of system costs



OE Energy Storage Program Scope



To accelerate the development and adoption of energy storage the OE-Energy Storage Program is working across the entire technology development cycle



Challenges for Grid Energy Storage

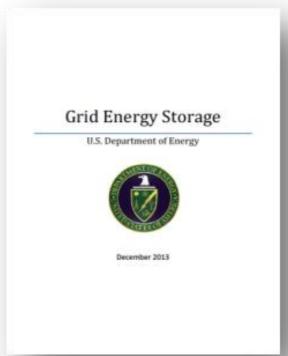


During the commissioning hearings of Dr. Moniz to head US DOE, Senator Wyden requested a strategic plan for grid energy storage.

DOE Published the report in December 2013

Four Critical Challenges were identified

- 1. Cost Competitive Energy Storage Technologies
- 2. Validated Reliability and Safety
- 3. Equitable Regulatory Environment
- 4. Industry Acceptance



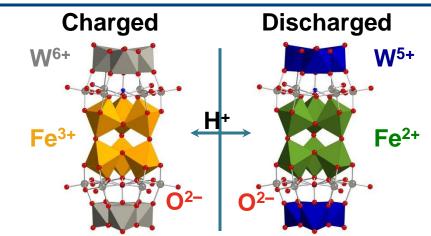
Cost Competitive Energy Storage Technologies





Ionic Liquid Flow Battery

Metal ionic liquid flow batteries may offer higher energy densities compared to aqueous flow batteries due to larger voltage windows and higher active material concentrations, but are limited by their viscosity. Project is revolutionizing flow batteries through new multivalent solutions and cell designs.



New metal oxide anions added to MetILs gave a 20% improvement in Coulombic efficiency over first generation non-aqueous materials and a 15% increase in active material utilization.

Target Non-Aqueous: 2 V Cell Fe MetIL (cathode)/W MetIL (anode)

Laboratory-scale test cells have interdigitated designs to optimize cycle life, voltage, and coulombic efficiency.

FY14-15 Accomplishments To Date

- As of FY15, published 8 articles and 13 conference papers-leading edge R&D
- Developed new membrane materials to reduce self-discharge by 50%-improved reliability
- Increased emphasis on iron-based compoundsenergy security; nontoxic

FY15-FY16 Plans

- Move towards commercialization through
 - Robust membranes for higher cycle life (>500 cycles)-materials compatibility
 - Increasing charge/discharge rates through higher surface area cells-lower R&D cost
 - Reducing over-voltages through interdigitated cell design-reduced cell wear

Cost Competitive Energy Storage Technologies





Sodium-Based Battery Chemistries

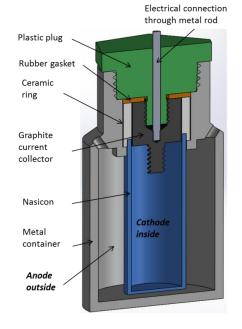
Motivation:

- Low cost (<\$100/kWh), low temperature (≤ 120°C), safe alternatives to Na-sulfur batteries
- High energy per unit weight and volume Small devices;
- Very low materials cost projected cost < \$100/kWh;
- Nontoxic; Ambient (25°C) or warm (120°C) operation;
- U.S. has large reserves of sodium Energy Security;
- Na-ion conducting separators (Nasicon) commercially available (Ceramatec, others) Lower R&D cost;
- Various cathode material couples
 - 120°C Na-I (organic electrolyte), 25°C Na-air (aqueous).

FY14-15 Accomplishments:

- Built 100 W-h sodium-ion cell & initiated long-term cycling
- >200 cycles of large sodium-ion cell with 87.5% efficiency
- Developed cost basis analysis tool for large scale battery and performed sensitivity analysis for Na-I vs. Na-Br
- 2 papers published, 4 sodium battery patent applications
- Demonstrated bulk and thin film NaSICON separators;
- Developed water-compatible NaSICON separators with improved alkaline stability (enables Na-air batteries)
- Safety testing protocol established for sodium batteries

20 Wh, 120°C molten Na vs. Na-I battery





NaSICON structure:
(Na₄Zr₂Si₂PO₁₂)
Sodium (Na)
Super Ionic CONductor
Channel size controls Na
conductivity – enhanced
30X via chemical doping

FY15-16 Plans:

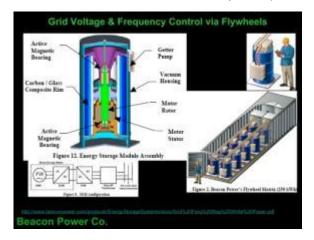
- Scale-up of cell size to 250 W-h sodium-ion cells
- NMR analysis of sodium transport mechanism and improving conductivity of Nasicon thin film separators
- Extend cost basis & safety tool to other batteries
- Demonstrate safety basis for sodium system
- Extend safety basis tool to other batteries (Na-air, Li ion)
- · Head to head safety basis analysis (Li vs. Na etc.)

Cost Competitive Energy Storage

Nano Composite Flywheels



Purpose: Improve the overall strength of composite flywheel materials, so they can spin faster.

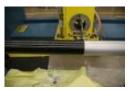


$$E_k = \frac{1}{2} \bullet I \bullet \omega^2$$

$$s_t = \rho \bullet r^2 \bullet \omega^2$$

Small % changes in the flywheel spin speed leads to magnified energy storage

Procedure: Carbon Fiber/ Nanomaterial Resin Winding









- 1. Materials Synthesis
- 2. Composite Fabrication
- 3. Mechanical Testing
 Test Samples



Flywheel nano-composite (Boyle-Lambert)-TiO₂ composite hub being fabricated















FY15 accomplishments:

- 1. Synthesis of 5Kg of nano particles
- Mailbox flywheel being fabricated

FY16 milestone:

- Test flywheel to determine actual strength of nano composite in flywheel
- Begin talks with flywheel companies of Sandia technology and possible partnering

Cost Competitive Energy Storage/ Validated Reliability & Safety





Energy Storage Power Electronics Program

Using wide bandgap semiconductor devices, advanced topologies, and controls to significantly reduce installed cost and footprint, improve control capability, and increase reliability

FY15 Accomplishments

- Developed world's first high voltage (15kV at 100 amps, 200C) SiC multichip module
- Developed world's first normally-off 6.5 kV SiC Junction Field Effect Transistor (JFET) high voltage module
- Developed route for direct fabrication of advanced transformer cores for > 20 kHz high frequency converters
- Developed design for a 60 kW,480V, 3-phase GaNbased inverter for energy storage

Recognition

- Four R&D100 Awards
- Three U.S. Patents, three pending
- Over 40 technical publications
- Power Electronics for Renewable & Distributed Energy Systems book

FY15-16 Plans

- Transition the SiC high voltage module into a manufactured product and commercialize
- Demonstrate continuous operation of the 6.5kV JFET module at 20 kHz, 60A, 200C for next generation ESS
- Optimize synthesis and fabrication of advanced transformer cores to maximize performance of high frequency DC-link converters
- Demonstrate a GaN-based inverter for ES greater than 98% efficiency and greater than 2X power density





Grid Energy Storage Safety Initiative

Motivation:

- In conjunction with stakeholders, DOE-OE identified *Validated Safety* as a critical need for the successful adoption of grid energy storage.
- Energy Storage Safety involves wide range of stakeholders including: developers, utilities, regulatory officials, certification agencies, insurance and first responders

FY14-15 Accomplishments:

- DOE OE Energy Storage Safety Workshop, February 2014
- DOE OE Webinar on Energy Storage Safety, April 2014
- Safety Panel ESA Annual Conference, June 2014
- DOE OE Strategic Plan on Energy Storage Safety, December 2014 http://energy.gov/oe/downloads/energy-storage-safety-strategic-plan-december-2014
- DOE OE Webinar on Strategic Plan on Energy Storage Safety January 2015
- DOE OE ESSWG Formed March 2015
- Developed interactive webpage to foster community engagement and provide up-to-date information. http://www.sandia.gov/ess/safety.html



February 2014 Safety Workshop Albuquerque, NM

> Strategic Safety Plan December 2014

Energy Storage Safety Strategic Plan

U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability

Department 2014

FY15-16 Plans:

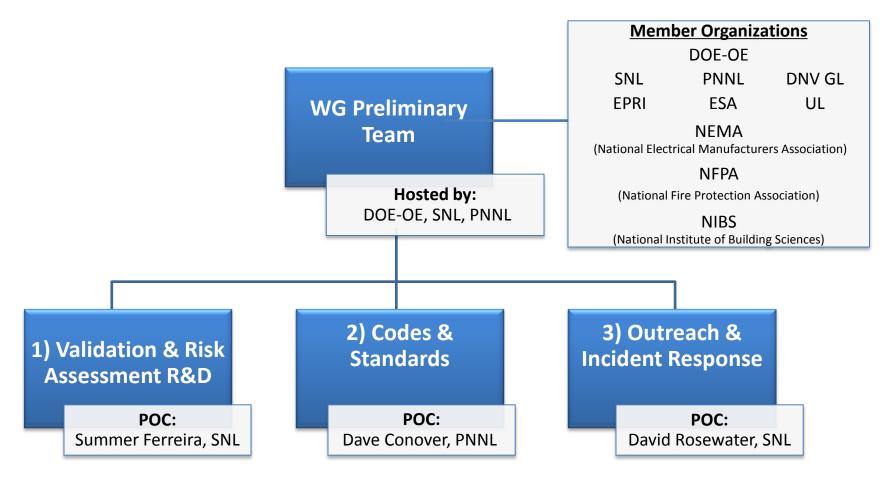
- Initiate ES Safety Forum with representatives from stakeholder groups to coordinate safety development.
- Initiate research on science of materials safety and cascading component failures
- Expand and lead quarterly ES Safety Forum (FY16)





Energy Storage Safety Working Group (ESSWG) Organizational Structure





Identified three immediate subject areas and a short list of top priorities in each area.





R&D Prioritization



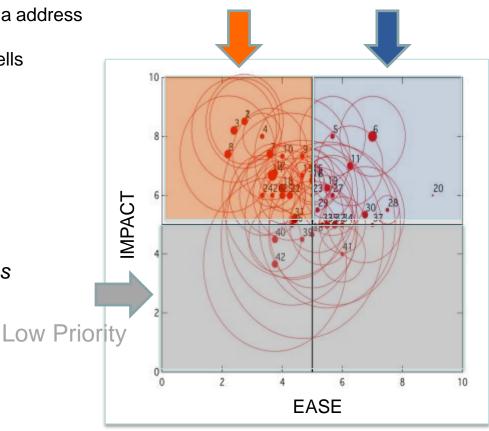
Industry

Key need – Identify <u>R&D efforts that will have the largest impact</u> on the safety of the industry. Safety

Safety Validation and Risk Assessment Quad Chart

Federal R&D

- Work to date
 - Ongoing work in labs, industry and academia address safety in an ad hoc manner.
 - Focused largely on performance of single cells
- Short term priorities identified:
 - Fire Suppression testing and analysis
 - Thermal runaway research
 - System scale burn test
 - Commodity classification development
 - Fire and vent gas modeling and analysis
- Longer term priorities: as resources allow.
 - DC fusing recommendations
 - How to handle stranded energy
 - Access control guidance
 - Guide to ESS safety analysis
 - R&D to address gaps found in standards









Codes Standards and Regulations Prioritization

Top Issues in Codes and Standards

- A single standard is needed to cover energy storage system installations
 - •It was identified that a single source reference standard would be the most impactful means of ensuring safety in new energy storage installations.
 - A pre-standard developed now may expedite the typically lengthy development process
- Triage and develop updates to existing codes and standards
 - Existing standards could be updated based on the developed source document as applicable to energy storage systems
- Develop guidance for documenting and validating energy storage system safety under existing codes and standards
 - Document and verify the acceptability of energy storage systems under current standards and model codes





Outreach Prioritization



 Key need – the ability to make safety critical information accessible to all stakeholders including first responders, inspectors, and regulators

Work to date

- Energy Storage Safety Meeting
- Energy Storage Safety Strategic Plan
- Ad-hoc engagement and collaboration between national labs, and industry on safety

Short term activities

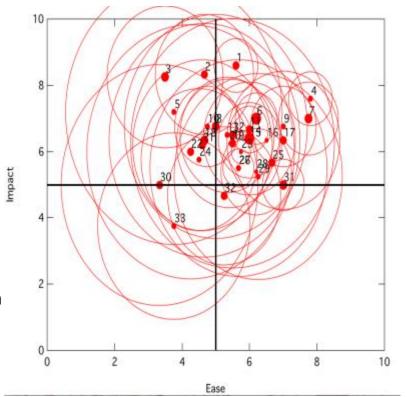
- Guidance and information on ESS installation and protection design
- Guidance and information operational safety
- Develop first responder training material

Longer term activities

- First responder knowledge and confidence through demonstrations, videos, guides, and courses
- Guidance and information on safe transportation

Safety Outreach and Incident Response

Quad Chart









Energy Storage Safety Working Group (ESSWG)

- All ESS stakeholders were invited to participate in these working groups.
- Each WG established a path forward and worked towards relevant goals as outlined in the slides on R&D, CSR and Outreach. Work started immediately.
- Visit the website for more information.

sandia.gov/ess/safety.html



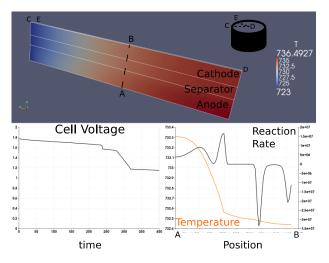


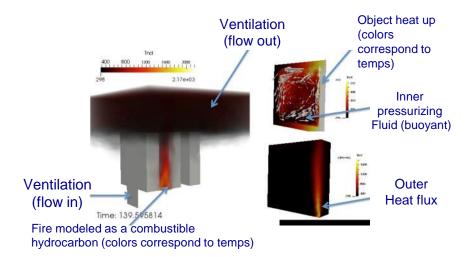
Modeling: Components through Systems

Modeling thermal events in a cell

Model of fire propagation between storage packs

Model linking battery performance with thermal environment



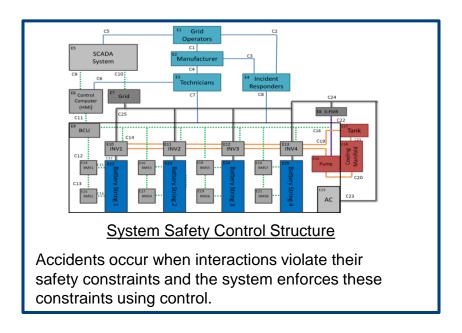


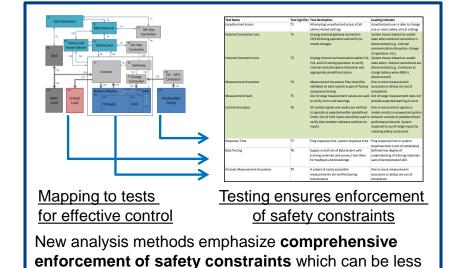
 Sandia has been using it's linked chemical / mechanical modeling capability to study failure in components through full systems.





Current methods for analyzing safety and controlling risk are difficult to implement on new and rapidly changing technologies. Project is developing advanced methodologies for analyzing safety holistically in energy storage systems.





FY15 Accomplishments To Date

Presentation at Battery Safety 2014 Conference



Positive feedback from developers, utilities, accident investigators and first responders.

FY15-16 Plans

 Teach short course on advanced methodologies and enforcement of safety constraints at Next Gen. Batteries conference

costly and more effective than alternative methods.

 Publish article on systems safety applied to a lithium-ion community energy storage device

Equitable Regulatory Environment

California

Motivation:

- Aggressive renewable portfolio standards – 33% by 2020
- Variability of wind/solar presents grid integration challenges:
 - Frequency and voltage regulation
 - Increased reserve requirements

Solution:

- California Public Utilities
 Commission (CPUC) Decision
 - 1325MW of energy storage
 - Procured by 2020
 - Installation by 2024
 - Targets for utilities
 Pacific Gas & Electric
 Southern California Edison
 San Diego Gas & Electric

580MW 580MW 165MW







Southern California Edison Tehachapi Storage System

Analysis – How Much Storage? Where?:

- Sandia is developing software for:
 - optimal placement/sizing of energy storage
 - Valuation of energy storage
- California has a market CAISO
 - Energy, ancillary services
 - Market data can drive some analysis
- Stochastic optimization better captures renewable variability
- Developing open-source Pythonbased tools

Equitable Regulatory Environment

U.S. DEPARTMENT OF ENERGY

Hawaii

Motivation:

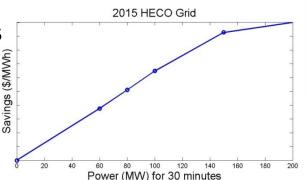
- Oahu derives the majority of its electricity from:
 - Diesel
 - Coal

This is Expensive!/ with a large carbon footprint

- There is a desire to significantly increase renewable generation
 - Large scale wind farms
 - Rooftop solar
- Variability of wind/solar presents grid integration challenges:
 - Frequency & voltage regulation
 - Increased reserve requirements

Solution:

- HECO issues RFP NO. 072114-01
- 60-200MW of energy storage
- 30 minute duration





HECO power plant at Kahe Point in West Oahu

Preliminary production cost modeling results, storage provides arbitrage and spinning reserve (includes frequency regulation)

Analysis – How Much Storage?:

- Production cost modeling
 - Optimizes generation mix to minimize system costs
 - Evaluate different storage scenarios
- Results for 2015 scenario (above)
 - Storage lowers costs
 - Analysis of increased renewable penetrations in progress (increased savings)

Industry Acceptance

DOE Outreach/Industrial Tools





Motivation:

- The DOE Global Energy Storage Database provides free, up-to-date information on gridconnected energy storage projects and relevant state and federal policies.
- The DOE/EPRI Electricity Storage Handbook is a how-to guide for utility and rural cooperative engineers, planners, and decision makers to plan and implement energy storage projects safety in communities
- The DOE Performance Protocol focuses on developing uniform methods of measuring ESS performance for specific applications.

FY14-15 Accomplishments:

- DOE Database (since 2012)
 - 1,206 Projects, 21 Policies and Users in 189 countries
 - 50+ Energy Storage Technologies
 - Data Visualization Tools

DOE/EPRI handbook

- Downloaded over 2,700 times during first month from US and overseas servers
- Continually updated in conjunction with EPRI, NRECA and feedback from industry.

Performance Protocol

Developed (2) new protocols for μgrids and PV smoothing



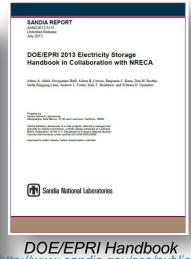
DOE Energy Storage Database www.energystorageexchange.org

FY15-16 Plans:

- DOE Database
 - Expand Database to include Safety Codes and Standards
- DOE/EPRI Handbook
 - Expand technology base to new technologies such as flow batteries
 - Integrate content from EPRI Energy Storage Integration Council (ESIC)

Performance Protocols

Revise and update previous protocols, select new protocols for development



tp://www.sandia.gov/ess/publications/SAND2013-5131.pdf



DOE OE Performance
Protocol

Industry Acceptance





The Energy Storage Systems Analysis Laboratory (ESSAL)

Providing reliable, independent, third party analysis and verification of advanced energy technologies for cell to MW systems

Cells and Modules



- 72V 1000A Bitrode (2 Channels)
 Cell, Battery and Module Analysis
- 14 channels from 36 V, 25 A to 72 V, 1000 A for battery to module performance analysis
- Over 125 channels; 0 V to 10 V, 3 A to 100+ A for cell performance analysis
- Potentiostat/galvanostats for spectral impedance
- Multimeters, shunts and power supply for high precision testing
- Temperature chambers

Fully Integrated Systems Lab Analysis Field Analysis (new)



Energy Storage Test Pad (ESTP)

- Scalable from 5 kW to 1 MW, 480 VAC, 3 phase
- 1 MW/1 MVAR load bank for either parallel microgrid, or series UPS operations
- Subcycle metering in feeder breakers for system identification and transient analysis
- Thermal imaging
- System Safety Analysis (new)



Remote Data Acquisition System (RDAS)

- Portable, Modular, Remotely Reconfigurable, and outdoor-ready
- Subcycle metering
- Tractable calibration
- Command Signal Ready for Grid
 Operator Simulation
- No control over grid conditions

SNL Industry Collaborations



Beacon Power, Helix

SunEdison

Arkansas Power Electronics Int., GeneSic Semiconductor, United SiC, Princeton Power

DRS Research, HRL, Sigma Technologies International

ESA

Hawaiian Electric Company / Maui Electric Company (HECO/MECO)

Sprint, RedFlow

Aquion Energy, Pennsylvania Department of Energy

Kodiak Electric Association (KEA)

Milspray Military Technologies, Princeton Power Systems, Raytheon/Ktech, GS Battery, Earl Energy

Duke Energy, Fiamm

PNM, NEDO, MDS, East Penn

CPUC, SunPower/DNV-GL/UCSD, ICE

SNL University Collaborations

Colorado School of Mines, University of Maryland

Oregon State University

Iowa State University

University of California: San Diego, LA, Davis

Case Western Reserve University

The State University of New York, University of New Mexico

Arizona State University, Iowa State University

Drexel University

North Carolina State University

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